

DISTANCE/RANGING BY DETERMINATION OF RF PHASE DELTA

FIELD OF THE INVENTION

The present invention relates to radio frequency identification tags (RF tags), and in particular, to an RF communication system and method for locating RF tags.

5 BACKGROUND OF THE INVENTION

Remote communication utilizing wireless equipment typically relies on radio frequency (RF) technology, which is employed in many industries. One application of RF technology is in locating, identifying, and tracking objects, such as animals, inventory, and vehicles.

10 RF identification (RFID) tag systems have been developed that facilitate monitoring of remote objects. As shown in Figure 1, a basic RFID system 10 includes two components: an interrogator or reader 12, and a transponder (commonly called an RF tag) 14. The interrogator 12 and RF tag 14 include respective antennas 16, 18. In operation, the interrogator 12 transmits through its antenna 16 a radio frequency interrogation signal 20 to the antenna 18 of the RF tag 14. In response to receiving the interrogation signal 20, the RF tag 14 produces an amplitude-modulated response signal 22 that is transmitted back to the interrogator 12 through the tag antenna 18 by a process known as backscatter.

15 The conventional RF tag 14 includes an amplitude modulator 24 with a switch 26, such as a MOS transistor, connected between the tag antenna 18 and ground. When the RF tag 14 is activated by the interrogation signal 20, a driver (not shown) creates a modulating signal 28 based on an information code, typically an identification code, stored in a non-volatile memory (not shown) of the RF tag 14. The modulating signal 28 is applied to a control terminal of the switch 26 which causes the switch 26 to alternately open and close. When the switch 26 is open, the tag antenna 18 reflects a portion of the interrogation signal 20 back to the interrogator 12 as a reflected portion 30 of the response signal 22. When the switch 26 is closed, the interrogation signal 20 travels through the

switch 26 to ground, without being reflected, thereby creating a null portion 32 of the response signal 22. In other words, the interrogation signal 20 is amplitude-modulated to produce the response signal 22 by alternately reflecting and absorbing the interrogation signal 20 according to the modulating signal 28, which is characteristic of the stored information code. The RF tag 14 could also be modified so that the interrogation signal is reflected when the switch 26 is closed and absorbed when the switch 26 is open. Upon receiving the response signal 22, the interrogator 12 demodulates the response signal 22 to decode the information code represented by the response signal.

The substantial advantage of RFID systems is the non-contact, non-line-of-sight capability of the technology. The interrogator 12 emits the interrogation signal 20 with a range from one inch to one hundred feet or more, depending upon its power output and the radio frequency used. Tags can be read through a variety of substances such as smell, fog, ice, paint, dirt, and other visually and environmentally challenging conditions where bar codes or other optically-read technologies would be useless. RF tags can also be read at remarkable speeds, in most cases responding in less than one hundred milliseconds.

A typical RF tag system 10 will contain a number of RF tags 14 and the interrogator 12. There are three main categories of RF tags. These are beam-powered passive tags, battery-powered semi-passive tags, and active tags. Each operates in fundamentally different ways.

The beam-powered RF tag is often referred to as a passive device because it derives the energy needed for its operation from the interrogation signal beamed at it. The tag rectifies the field and changes the reflective characteristics of the tag itself, creating a change in reflectivity that is seen at the interrogator. A battery-powered semi-passive RFID tag operates in a similar fashion, modulating its RF cross section in order to reflect a delta to the interrogator to develop a communication link. Here, the battery is the source of the tag's operational power. Finally, in the active RF tag, a transmitter is used to create its own radio frequency energy powered by the battery.

The range of communication for such tags varies according to the transmission power of the interrogator 12 and the RF tag 14. Battery-powered tags operating at 2,450 MHz have traditionally been limited to less than ten meters in range. However, devices with sufficient power can reach up to 200 meters in range, depending on the frequency and environmental characteristics.

Although prior art communication systems can communicate with an RF tag that is within a certain distance of the interrogator (depending on the interrogator power), the interrogator cannot determine the location of the RF tag. For example, the prior art interrogator may be able to determine that there is an RF tag within 100 meters of the interrogator, but cannot determine whether it is 90 meters away or 45 meters away. In addition, the prior art interrogator cannot determine whether the RF tag is in front of, behind, or to either side of the interrogator. There are numerous applications for which such location information is important.

SUMMARY OF THE INVENTION

Embodiments of the present invention are directed to a method and system for locating an RF transponder. The method transmits from a first transponder to a second transponder first and second signals at different frequencies, respectively. The second signal is compared with the first signal and a distance between the first and second transponders is determined based on a phase difference between the first and second signals. In one embodiment, the first transponder is an interrogator, the second transponder is an RF tag, and the RF tag determines the phase difference between the two signals. In another embodiment, the first and second transponders are the interrogator and RF tag, respectively, but the interrogator determines the phase difference between the two signals after the two signal are reflected back to the interrogator. Alternatively, the roles of the interrogator and RF tag are reversed in other embodiments.

The comparison and determination of a phase difference between the two signals are performed in one embodiment by phase locking one the first signal to produce a

reference signal. The reference signal is then mixed with the second signal to produce a mixed signal. A counter determines the phase difference by counting the number of nulls or peaks in the mixed signal, the nulls corresponding to respective portions of the signals that are of opposite phase to each other and the peaks corresponding to respective portions of the signals that are in phase with each other. The number of nulls or peaks within a period is directly related to the distance between the interrogator and the RF tag. In a preferred embodiment, the second signal is a frequency modulated signal that includes plural frequency portions each at different frequencies and the counter counts nulls or peaks in plural different mixed signals produced by mixing the respective frequency portions with the reference signal.

The method can also determine a position of the RF tag by measuring the distances from two different locations of the interrogator to the RF tag. In one embodiment, the two distances are measured from two spaced-apart antennas of the interrogator. In another embodiment, the interrogator is moved from one known location to another known location. With distance measurements from both known locations, the location of the RF tag can be determined by simple geometry.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a prior art RF communication system employing amplitude-modulated backscatter signals.

Figure 2 is a schematic diagram of an RF communication system for locating an RF tag according to an embodiment of the present invention.

Figure 3 is a schematic diagram of a phase comparison circuit employed in the system of Figure 2.

Figure 4 is an alternate embodiment of an interrogator for use in the system of Figure 2.

Figure 5 is an alternate interrogator for locating an RF tag according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As shown in Figure 2, an embodiment of the present invention is directed to an RF communication system 34 that determines a distance between a reader or interrogator 36 and an RF transponder or tag 38. The system 34 determines the distance by transmitting from the interrogator 36 to the RF tag 38 a first signal 40 at a first frequency and a frequency modulated second signal 42 at a second frequency. The RF tag 38 compares the signals 40, 42 and determines a phase difference between the two signals. The distance between the interrogator 36 and the RF tag 38 is directed related to that detected phase difference.

The interrogator 36 includes a controller 44, a variable signal source 46, a tapped transmission line 48, a signal analyzer 50, and an antenna 52. The controller 44 can be any general purpose processor, such as a known microprocessor, or can be specifically designed to control the operation of the interrogator 36 as described herein. Examples of the tapped transmission line 48 and signal analyzer 50 can be found in U.S. Patent No. 4,360,810 to Landt, which is incorporated by reference herein in its entirety. The tapped transmission line 48 enables the single antenna 52 to be used to transmit and receive signals simultaneously. Of course other systems for receiving and decoding the response signal from the RF tag 38 could be employed, such as the system shown in U.S. Patent No. 4,075,632, which is incorporated herein by reference.

The RF tag 38 includes a controller 54, a memory 56, a modulating switch 58, an antenna 60, a phase comparison circuit 62, and a mode switch 64. The controller 54 can be any general purpose processor, such as a known microprocessor, programmed to control the operation of the RF tag 38 as described herein or can be specifically designed to provide the control functions. The mode switch 64 alternately couples the antenna 60 to either the modulating switch 58 or the phase comparison circuit 62 under the control of the controller 54 as discussed in more detail below.

Stored in the memory 56 is an information code, such as an identification code that identifies the RF tag 38 and/or an object to which the RF tag is attached.

Alternatively, the information code could represent numerous other pieces of information, such as the environmental conditions surrounding the RF tag 38, inventory information associated with the RF tag, or information that was previously written to the RF tag before or after the RF tag was placed into service. The memory 56 can be implemented with any
5 type of memory, but preferably is non-volatile memory so that the information code is not lost when power is lost.

During a tag identification mode, the interrogator 36 transmits a continuous wave interrogation signal to the RF tag 38 in an attempt to determine the identity of the RF tag. Based on the identification code stored in the memory 56, the controller 54 of the RF
10 tag 38 creates a modulating signal that is applied to the modulating switch 58, which modulates the interrogation signal to produce a backscatter response signal that is transmitted back to the interrogator 36. The modulation of the interrogation signal can be amplitude-modulation as described above with respect to Figure 1 or can be phase-modulation as described in a United States Patent Application entitled Phase Modulation in
15 RF Tag, which is being filed on the same date as the present application under attorney docket number E1804 and which is incorporated herein by reference.

The response signal from the RF tag 38 is received by the interrogator 36 and mixed with the interrogation signal in the tapped transmission line 48. The tapped transmission line 48 and signal analyzer 50 combine to demodulate the response signal to
20 determine the information code of the RF tag 38 and pass the information code to the controller 44. The controller 44 determines whether the information code is valid, and if so, transmits an acknowledgement signal to the RF tag 38.

After the interrogator 36 acknowledges receipt of the information code, the RF tag 38 switches into a distance determination mode by coupling the phase comparison
25 circuit 62 to the antenna 60 via the mode switch 64. In the distance determination mode, the interrogator 36 transmits the first and second signals 40, 42 to the RF tag 38. In a preferred embodiment, the second signal 42 is transmitted after the first signal 40 is transmitted, but the signals could be transmitted simultaneously by separate antennas

without departing from the invention. The controller 44 of the interrogator 36 can be programmed to cause the variable signal source 46 transmit only the first signal 40 at the first frequency followed by the second signal 42 at the second frequency. Alternatively, the controller 44 can be programmed to cause the signal source 46 to transmit a frequency
5 ramp that starts at the first frequency and includes the second frequency, that is, the first and second signals 40, 42 can be part of the frequency ramp. Or, the signal source 46 can randomly or pseudo-randomly changes frequencies to transmit the first and second signals 40, 42. The invention includes any combination of two or more frequencies.

The phase comparison circuit 62 of the RF tag 38 compares the signals 40,
10 42 and determines a phase difference between the two signals. The distance between the interrogator 36 and the RF tag 38 is directed related to that detected phase difference. The phase comparison circuit 62 passes to the controller 54 information indicative of the phase difference, which the controller can use to compute the distance between the interrogator 36 and the RF tag 38.

15 Shown in Figure 3 is a more detailed diagram of the phase comparison circuit 62 of the RF tag 38. The phase comparison circuit 62 includes a signal divider 66, phased lock loop 68, mixer 70, and null/peak counter 72. The signal divider 66 divides the incoming first signal 40 into two identical signals, one of which going to the phase lock loop 68. The phase lock loop 68 phase locks, and preferably amplitude locks, on the
20 incoming signal to produce a reference signal that is substantially identical to the incoming first signal 40. The phase lock loop 68 preferably is selected to provide a robust phase lock with a long lock and hold capability. The reference signal is passed to the mixer 70 which also receives the other one of the signals from the signal divider 66 and produces a mixed output signal that is a combination of the two signals input to the mixer. Initially, the
25 mixed output signal is a combination of the first signal 40 received from the signal divider 66 and the reference signal, which is substantially identical to the first signal 40, so the mixed output signal is equal to the first signal 40 except with larger peaks and valleys.

When the signal received by the phase comparison circuit 62 changes from the first signal 40 to the second signal 42, the mixer 40 receives at one input the second signal 42 from the signal divider 66 and at the other input the reference signal which is substantially identical to the first signal 40. The mixer 70 combines the second signal 42 with the reference signal, resulting in a mixed output signal with two frequency components. At regular points in time and space, the second signal 42 will be at a maximum while the reference signal is at a minimum, resulting in null points in the mixed output signal. Consecutive null points of the mixed output signal will be separated by peak points at which both the second and reference signals are at a maximum, or both are at a minimum. The null/peak counter 72 counts either the null points or the peak points in the mixed output signal and provides the resulting count to the controller 54. The null/peak counter 70 can be either an analog counter or can include an analog/digital converter and a digital signal processor to determine the count digitally.

In one embodiment, the frequencies of the first and second signals 40, 42 are known to the controller 54, and thus, the controller uses the count provided by the null/peak counter 72 to compute the distance between the interrogator 36 and the RF tag 38. Alternatively, the controller can incorporate the count into a count signal that is transmitted by the RF tag 38 back to the interrogator 36. The controller 44 would then use the count and the frequencies of the first and second signals 40, 42 to determine the distance between the interrogator 36 and the RF tag 38.

An important aspect is the fact that both backscatter and transmitter systems can determine the distance between an interrogator and an RF tag and the location of the RF tag using such phase differences and null/peak counts.

An example may help one to understand how the distance between the interrogator 36 and RF tag 38 can be determined. A first signal at 880 MHz has a wavelength of 34.0909091 cm and a second signal at 884 MHz has a wavelength of 33.9366516 cm. At a distance of about 37.5 meters (110 wavelengths of the first signal and 110.5 wavelengths of the second signal), the first and second signals will be 180

degrees out of phase, resulting in a null point in the mixed signal output by the mixer 70. At each additional 75 m, there will be an additional null point, and thus, the distance between the interrogator 36 and the RF tag 38 can be determined with an accuracy of +/- 37 m using a first signal at 880 MHz and a second signal at 884 MHz.

5 The accuracy can be improved by using a frequency modulated second signal rather than keeping the second signal at only the second frequency. For example, assume the second signal includes a first portion at 883 MHz, a second portion at 884 MHz, and a third portion at 890 MHz. Mixing each of those portions of the second signal with the first signal results in first, second, and the mixed signals with nulls at distances of
10 50, 37.5, and 15 meters, respectively. Therefore, if the counter counts 1 null for each of the first and second mixed signals and 3 nulls for the third mixed signal, then the controller can determine that the distance between the interrogator 36 and RF tag 38 is between 50 and 60 meters. If the distance were less than 50 meters, then the first mixed signal would have had no nulls; and if the distance were more than 60 meters, then the third mixed signal would
15 have had 4 nulls. Of course, with more than three frequency portions of the second signal, the accuracy of the distance determination can be improved further. Moreover, rather than comparing all frequency portions of the second signal to the first signal, one could compare some of the frequency portions with each other.

 In one embodiment, the interrogator 36 employs a quarter-wave dipole
20 antenna as the antenna 52, but any type of antenna could be employed. In another embodiment, the antenna 52 is a phased-array antenna, which enables the interrogator 36 to determine the direction of the RF tag 38 relative to the interrogator. By determining both the direction and distance of the RF tag 38 relative to the interrogator 36, the interrogator accurately determines the location of the RF tag 38.

25 Shown in Figure 4 is an alternate interrogator 36A that can determine the direction and distance of the RF tag 38 relative to the interrogator 36A without employing a direction-determining antenna like the phased-array antenna. Instead, the interrogator 36A employs first and second antennas 52A, 52B that are each connected by an antenna

switch 74 to the same tapped transmission line 48 as in the interrogator 36 of Figure 2. To determine the location (distance and direction) of the RF tag 38, the interrogator 36A determines first and second distances from the first and second antennas 52A, 52B, respectively, to the RF tag according to the same scheme as described above. That is, the
5 interrogator 36A first transmits the first and second signals via the first antenna 52A, the RF tag 38 counts the nulls in the mixed signal output from the mixer 70, and the controller 44 calculates the first distance; and then the process is repeated using the second antenna 52A to determine the second distance. The controller 44 controls which antenna 52A, 52B is used at a time by controlling the antenna switch 74. The controller 44 uses the first and
10 second distances and the known distance between the two antennas 52A, 52B to compute the location of the RF tag 38 using simple geometry.

Shown in Figure 5 is another alternate interrogator 36B that can locate (distance and direction) the RF tag 38 or any prior art RF tag without modifications to the prior art RF tags. The interrogator 36B includes, in addition to the same elements 44-52 of
15 the interrogator 36 of Figure 2, a position input device 76, and the null/peak counter 72. The position input device 76 inputs to the controller 44 the positions of the interrogator 36B at two different locations. The interrogator 36B takes a distance measurement to the RF tag at each of the two different locations of the interrogator and uses those distance measurements, together with the position information provided by the position input device
20 76, to compute the location of the RF tag. The position input device can be a simple keyboard or other device through which a user inputs in the position of the interrogator or can be an accelerometer or other device that measures a position change from a first location to a second location of the interrogator. Alternatively, the interrogator 36B can be moved between two locations for which position information is pre-programmed into the
25 controller 44 to avoid having to input new position information with each distance determination.

By incorporating the null/peak counter 72 in the interrogator 36B rather than in the RF tag 38, the interrogator 36B can determine the location of any RF tag. In the

distance determination mode, the controller 44 causes the variable signal source 46 to transmit the first and second signals 40, 42 via the antenna 52. The RF tag reflects and modulates the first and second signals 40, 42. The modulation is done to distinguish the RF tag from other objects such as metal cans or other reflecting objects. The reflected first
5 signal 40 is received by the antenna 52 and mixed with the second signal 42 by the tapped transmission line 48. The null/peak counter 72 counts the nulls or peaks in the mixed signal output by the tapped transmission line 48 and the controller 44 determines a first distance between the interrogator 36B and the RF tag based on the null or peak count. It should be appreciated that the distance determination algorithm used by the controller must
10 compensate for the fact that the total path length of the communication is now out and back.

The user then moves the interrogator 36B to a second location and the process is repeated to determine a second distance between the interrogator 36B and the RF tag. The controller 44 determines the location of the RF tag based on the first and second
15 distances and on the interrogator location information provided by the position input device 76. To facilitate its movement, the interrogator 36B, like the interrogators 36, 36A, can be provided as a hand-held device.

Although the embodiments shown in figures 2-5 show the interrogators 36, 36A, 36B incorporating the variable signal source 46, it should be appreciated that the roles
20 of the interrogator and the RF tag can be completely reversed. That is, the RF tag could transmit the first and second signals to the interrogator, and either the interrogator or the RF tag could perform any the distance determination functions. It may be preferable to incorporate many or all of the distance determination functions on the interrogator to keep the size of the RF tag to a minimum, but it is not essential to the invention.

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CLOSURE

In view of the foregoing, it will be appreciated that the RF communication system discussed herein provides important advantages over prior art systems. By

providing the ability to locate an RF tag, and any object attached to the RF tag, the RF communication system discussed above greatly extends the range of applications to which RF tag technology can be applied. For example, the RF communication system discussed above can be employed to locate lost weapons on a battlefield, animals across a large
5 property, and any inventory object within a warehouse.

Finally it will be clear that many modifications and variants may be introduced to the inventive embodiments described and illustrated herein, all of which come within the scope of the invention as defined in the accompanying claims.

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